THE EVALUATION OF NATIVE MARSH PLANT SPECIES FOR THE TREATMENT OF DOMESTIC SEWAGE

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ABSTRACT

Three species of emergent aquatic plants were compared for their ability to treat domestic sewage in an artificial marsh environment. The species evaluated were Typha angustifolia (narrow leaf cattail), Scirpus validus (bulrush), and Phragmites australis (common reed). Typha has been evaluated in a full-scale marsh treatment system at Port Perry, Ontario. The other two species, Scirpus and Phragmites, have not been evaluated in Canada.

Monoculture stands of each species were established in separate steel enclosures. Each cell measured 15 m x 1.5 m, providing a length to width ratio of 10:1. During 1986 and the winter of 1987, pre-treated sewage of a known quality was applied to each cell. A mix of raw sewage and partially treated lagoon effluent was used as influent for the experimental facility from May, 1987, to completion of the study in October, 1987. The effluent from each cell was sampled bi-weekly during the summer, and monthly during the winter. Standard wastewater parameters including D.O., BOD, S.S., H_2S, TP, ammonia, and TKN were measured.

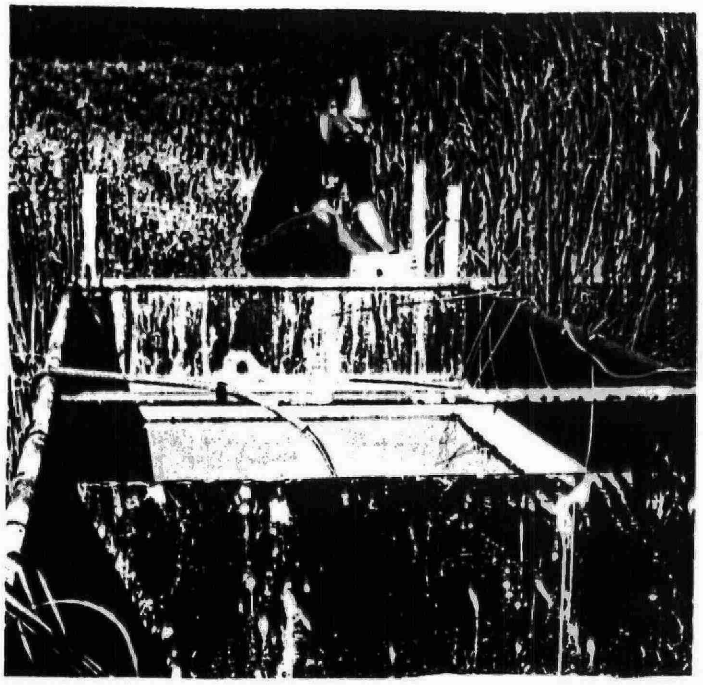
Effluent concentrations of BOD and suspended solids normally remained below 10 mg/L and 30 mg/L, respectively, during the summer periods. Removal of phosphorus and nitrogen was approximately 75% during the first summer. Efficiency of nitrogen and phosphorus removal in the Typha and Scirpus cell declined during the second summer (1987), but removal rates for both parameters remained above 60%. Oxygen concentrations normally remained above 1.5 mg/L in cell effluents, though H_2S concentrations in Typha and Phragmites effluent averaged 1.8 mg/L and 0.52 mg/L, respectively, during the second summer. Good reductions of fecal organisms was provided by all species. Winter treatment declined for suspended solids, TKN, and ammonia. Higher organic loading rates in summer, 1987, affected effluent quality for each species. Overall poorest treatment in both years was provided by Typha.

Dieback of Scirpus in the second year (1987) due to water level changes prevented further evaluation of treatment ability. Culture practices employed to initiate colonization of cells (planting density and water depth) were successful and documented.

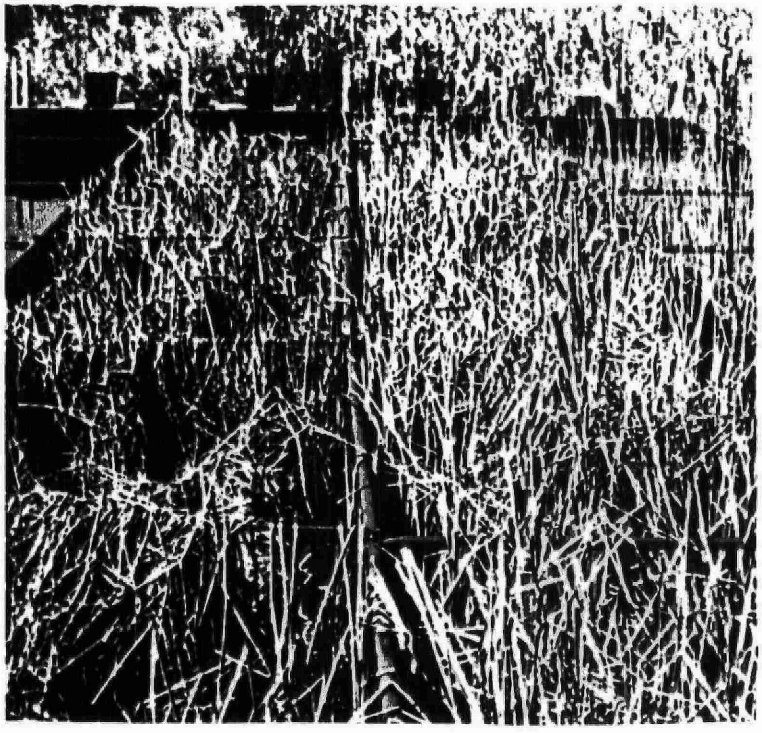
A fourth cell providing a control was converted to serve as a duckweed (Family:Lemnaceae) polishing cell in July, 1987. Effluent from the emergent plant cells provided influent for the duckweed polishing cell. Additional removal of ammonia (67%), TKN (49%), TP (61%) and other constituents, with the exception of suspended solids, was provided by the duckweed polishing cell. High concentrations of dissolved oxygen, and no H_2S, were obtained in effluent samples from the duckweed polishing cell.

Poor growth rates of duckweed experienced through most of the study, other than within the first two weeks, indicate further cultural information is required to establish the means by which duckweed may be successfully grown and harvested as an effluent polishing strategy.

Calibrating influent flow during the fall.



Duckweed polishing cell receiving marsh cell effluents.



Marsh cells during late fall.

Cultured Typha(l) and and Phragmites(r).

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Review of Literature Relating to Treatment of Domestic Wastewaters with Emergent Aquatic Plants

Treatment of domestic wastewater with artificial marshes has received extensive research attention for approximately twenty years (Wolverton, 1986). Some of the first research was undertaken in the West Germany at the Max Plank Institute using Scirpus lacustris for treatment of various wastewaters (Seidel, 1966) and subsequently Phragmites communis for reduction of sludges (Seidel, 1971). In Europe and the U.K., the present emphasis is on the use of Phragmites for wastewater treatment (Bix, 1987; Cooper and Hobson, 1987; Lawson, 1985). In the United States, various authors (Wolverton, 1986; Gersberg et al., 1986; Steiner et al., 1986; 1988; Watson et al., 1986) have described use of Phragmites and Scirpus as well as Typha in various types of artificial marshes for treatment of wastewaters in temperate climates.

Six species of Scirpus occur in North America. S. validus can achieve heights of 4 to 6m and occupy water depths to approximately 1m (Prescott, 1969). A description of shoot, stem and leaf development, and life history is given by Seidel (1966). Prescott notes that Scirpus stands serve as muskrat food, nesting sites for birds, and to bind substrates.

Two species of Typha occur in North America, T. latifolia and T. angustifolia. Both are widely distributed where marsh environments are present (Prescott, 1969), usually forming dense stands which offer

valuable habitat for wildlife. Voss (1972) provides a description of the ecology and lifecycle of each species.

Though two species of Phragmites (P. communis and P. australis) are described by some authors, Voss (1972) recognizes only one species, P. australis (Cav.) Steudel. Phragmites has world wide distribution and is common where wet soil conditions occur (Prescott, 1969). Phragmites can grow to 4m tall. A thorough description of Phragmites ecology is given by Lawson (1985) detailing habitat, growth and development, and physiology. Potential for O_2 transfer, biomass productivity (above and below ground), and management of Phragmites in artificial marshes is also discussed.

At present, three different types of artificial marshes are being employed and evaluated for treatment of wastewaters. Surface flow marshes such as employed at Listowel, Ontario (Herskowitz, 1986) and Port Perry, Ontario (Neil and Graham, 1987), operate with wastewater flowing over the surface of culture soils, submerging the roots, rhizomes and lower portion of the stems.

The other two types of marshes, the root zone method (RZM) and the Max Plank Institute or Krefeld process, employ below - grade flow of wastewaters through substrates of relatively high hydraulic conductivity (Lawson, 1985). The RZM method employs primarily Phragmites as the culture species. Wastewater flows along rhizome channels or through the soil medium which has the hydraulic conductivity increased by virtue of extensive proliferation of plant rhizomes (Kickuth in Lawson, 1985; Brix, 1987). In the Krefeld marsh system, wastewater flows through a rock or gravel medium. Cultured macrophytes include Phragmites, Typha, and Scirpus (Wolverton, 1986; Steiner et al., 1986; 1988; Gersberg, 1986). The rhizomes of the plants penetrate into the filter medium,

replicating a microbial filter system combined with cold - tolerant plants (Wolverton, 1986).

The RZM type treatament was developed and promoted largely by Kickuth in West Germany (Lawson, 1985). Soils are carefully selected as a rooting - filtration - adsorption medium. The soil is undersealed with an impervious liner or clay layer. Much of the water flows alongside living rhizomes or through pores created by old and decaying rhizomes. Oxygen translocated by plants is released by the rhizomes, creating aerobic and anaerobic zones in the soil profile. Plants serve primarily to facilitate O_2 transfer, maintain high hydraulic conductivity, and enhance conditions for microbial growth within the rooting zone, or rhizosphere (Kickuth in Lawson, 1985, Watson et al, 1986).

Several management problems have arisen with the RZM type marsh. Excessive weed growth can develop and effectively compete with developing Phragmites in early spring and summer. Hydraulic conductivity of soils may not increase as expected as rhizomes develop, resulting in surface flow and clogging in some installations (Cooper and Hobson, 1987). The degree to which Phragmites can translocate O_2 to the rhizosphere may be less than originally described (Lawson, 1985).

The Krefeld type of treatment system offers several advantages over the RZM. Sufficient hydraulic capacity is ensured by the use of gravel or rock substrate, allowing utilization of species other than Phragmites. Typha and Scirpus, among other plants, have been successfully cultured in Krefeld type systems (Wolverton 1986, Gersberg et al 1986, Watson et al 1986). Weed problems are minimized by the use gravel or rock (Cooper and Hobson, 1987). Brix (1987), however, indicates that gravel should not be used as a substrate as the use of

fine textured soils promotes adsorption of phosphorus and ammonia.

Treatment efficiencies of Krefeld marsh systems is well described in the literature. Good reductions of BOD and suspended solids is reported by most authors for systems utilizing Phragmites, Typha or Scirpus (Thiessen et al., 1986; Watson et al., 1986; Gersberg et al., 1986; Steiner et al., 1988; Bavour et al., 1986). Gersberg (1986) concluded that BOD reduction was facilitated by the presence of emergent plants, though removal of suspended solids was mainly by sedimentation or filtration. Removal of ammonia has been generally less acceptable, though failure to meet summer discharge criteria in one installation was attributed to organic loading exceeding design specifications (Steiner, 1988, pers. comm.). Poorer reduction of ammonia and phosphorus during the winter period was reported for a Typha system in Pennsylvania (Watson et al., 1986). Under experimental conditions, Wathugala et al., (1986) reported good reduction of phosphorus and nitrogen in wastewater treated by Phragmites growing in sand, providing better reductions of phosphorus and nitrogen than sand without plant growth.

Results of an experimental study comparing treatment efficiencies of Scirpus, Phragmites and Typha grown in gravel channels to reduce BOD, suspended solids and ammonia were reported by Gersberg et al. (1986). Of the three plant species, Scirpus provided the best reduction of BOD and ammonia, The next best treatment for both parameters was provided by Phragmites. All three species provided better reduction of BOD and ammonia than a control channel. Better reduction of BOD and ammonia by Scirpus and Phragmites was attributed to superior abilities to translocate O_2 to the rhizosphere. Removal of nitrogen was attributed to sequential nitrification - denitrification, as the amount of nitrogen contained within the plant biomass of Scirpus was minimal (12%-16%)

compared to the amount of nitrogen removed from the the waste stream. No significant difference was observed between the three plant channels or the control channel for removal of suspended solids, and the author attributed physical processes including sedimentation and filtration as principal mechanisms responsible for removing suspended solids.

A relatively small number of studies describing performance of RZM treatment systems have been published, though numerous sites treating domestic wastewaters have been established in the U.K. and Europe (Cooper et al., 1987). The Water Research Board based in the U.K. currently specifies 3-5 m^2 of Krefeld or RZM type Phragmites beds as being adequate to treat sewage from one person, with prior settling or screening (Cooper and Hobson, 1987). In a review of RZM systems performance in Denmark, Brix (1987) concluded that the majority of phosphorus removal occured by adsorption, and that adsorption of ammonia to soil particles rather than nitrification - denitrification was the principal mechanism of nitrogen removal from the waste stream. Removal of BOD was comparable to secondary treatment standards, though removal of phosphorus and ammonia was variable and dependent mainly on the composition of soils and degree of surface runoff.

Surface flow systems have recieved less research attention, and subsequently, relatively little performance information is available. Few operating systems have been reported. Herskowitz (1986) and Reed et al. (1984), describe treatment ability of surface flow systems utilizing Typha at Listowel, Ontario. Effluent concentrations of BOD and suspended solids normally remained below 10 mg/L. Ammonia removal declined during the summer, as did phosphorus in the summer and winter. Anoxic or low O_2 concentrations developed during the winter and summer. Dejong (in Lawson, 1985) summarizes treatment performance of a 1 ha pond

planted with Scirpus lacustris receiving diluted sewage from a campground. Water depth was maintained at 40 cm, and reduction of BOD, nitrogen and phosphorus was in excess of 90%. Winter performance information was not available, however, as the pond received wastewater only on a seasonal basis.

Good reductions of coliforms have been reported in most instances by marsh treatment systems. Seidel (1966) reports good reduction of coliforms in wastewater applied to the roots and rhizomes of Scirpus, and to a lesser degree with Phragmites. Other authors (Gersberg et al., 1986; Herskowitz, 1986; Steiner, 1988; Watson et al., 1986) have also reported good reductions of coliforms using marsh treatment. Various authors attribute the effectiveness of coliform removal to O_2 supplied to the rhizosphere by the plants (Seidel, 1986; Gersberg et al., 1986;) or by substances excreted by the plant roots that kill fecal coliforms. Poorer reductions of coliforms have been recorded from marshes when anoxic conditions develop (Herskowitz, 1986; Palmateer in Gersberg et al., 1986).

At present, research into artificial marsh systems is continuing in the U.K. and the United States. Three, full scale, demonstration systems treating domestic wastewater are being built or operated in Tennessee using surface flow, Krefeld, and RZM type marshes. Plant species including Scirpus, Phragmites and Typha are being employed (Steiner et al., 1988). Results of these operations should prove valuable in determining optimum design criteria and relative efficiency of culture species in different types of treatment systems. In the U.K., research continues into evaluating efficiency of RZM and Krefeld type systems utilizing Phragmites, and pursuing related information requirements including propagation, O_2 transfer rates, rhizosphere

microbial ecology, and specification of suitable soils (Cooper and Hobson, 1987). Of particular note is that U.K. scientists have developed methods to grow Phragmites from seed with nearly 100% success, facilitating ease of marsh planting.

Introduction

Treatment of domestic sewage by facultative lagoons is common practice for smaller communities in Ontario. As an alternative to traditional lagoon treatment, the Province of Ontario has conducted extensive research and demonstration projects to determine the advantages of utilizing emergent aquatic plants in artificial marshes as an alternative treatment of domestic sewage (Herskowitz, 1986).

Marsh systems provide treatment of wastewaters by both physical and biological processes. Biological treatment is achieved by uptake of nutrients by the plant canopy and by decomposition of organics in a microbial community established on the roots, stems and hydrosol. Physical treatment processes includes precipitation, absorption, and flocculation. Emergent plant species also have a variable ability to translocate oxygen to the root system, both in living plants and during the winter through hollow stem tissue. Oxygen released to the sediment and water column from plant rhizomes assists in maintaining an aerobic environment.

Initial investigations of marsh treatment systems were conducted at Listowel, Ontario, where lagoon effluent and aerated cell effluent was applied to various marsh system designs. Encouraging results from the Listowel study led to the development in 1985 of a full scale, demonstration artificial marsh at Port Perry, Ontario. At both locations, the cattail (Typha angustifolia) was selected as the treatment species because it grows vigorously in monoculture stands and it is a common, native species readily available for planting. Early

experimentation also suggested that this species was effective in treating wastewaters.

In addition to Ontario's two native species of cattail, two other emergent plants, Phragmites australis (Common Reed) and Scirpus validus (Soft Stem Bulrush), appear to meet the biological criteria necessary for successful marsh treatment. Both plants grow in dense monoculture stands, are native to Ontario and are capable of thriving in highly enriched aquatic environments. Research conducted principally in Europe indicates that Phragmites and Scirpus are effective at treating wastewaters in artifical marsh environments. However, there has been little investigation of the efficiency of Phragmites or Scirpus to treat domestic sewage in North America.

This study was initiated to evaluate these species through a direct comparison with narrow leaf cattail (Typha angustifolia) at the Port Perry sewage treatment facility. The study objectives were as follows:

1) To review and consolidate existing information on the use of these species for treatment of domestic sewage for waste treatment.

2) To establish identical small scale cells where a direct comparison of efficacy of treatment by three emergent plant species can be undertaken.

3) To manipulate hydraulic and organic loading in the experimental system to determine optimum operating conditions and effluent quality throughout the year.

4) To develop cultural practice that would provide practical guidance to any future full scale use of a selected species.

5) To use the comparative data developed from the experimental plots within the full scale marsh to predict treatment capability in a full operating system.

During 1987, a supplementary study was incorported into the research program. The primary objective of this substudy was to determine the effectiveness of a polishing cell supporting a floating cover of duckweed as a means to remove ammonia and phosphorus from marsh treatment system effluent.

Methods

The experimental marsh site was located adjacent to the existing demonstration marsh at Port Perry. Four steel cells were constructed, each 15 m by 1.5 m, providing a length to width ratio of 10:1. In the first year, monoculture stands of Phragmites, Typha, and Scirpus were established by transplanting root stock into three of the cells. The fourth cell served as a control. The four cells were loaded with a common influent. Figure 1 illustrates the physical layout of the experimental facility with the exception that the control cell is not shown.

Loading rates, water depths and theoretical retention times for Year 1 operation (August 1986 to February 1987) and Year 2 (May 1987 to October 1987) are given in Table 1. Water depth was controlled by standpipe height in each cell. For winter operation (November to May), all cell depths were adjusted to 30 cm, with corresponding retention times of 15 days.

Cell effluents were sampled twice monthly beginning in September 1986. Sample frequency was reduced to once a month beginning in November, and continued on a monthly basis during the winter. Bi-monthly sampling resumed in May, 1987 and continued until October 23, 1987.

Effluent samples from each cell were analysed (Beak Environmental Ltd.) for concentrations of BOD, suspended solids, total phosphorus, kjeldahl nitrogen and ammonia. Nitrate concentrations were determined

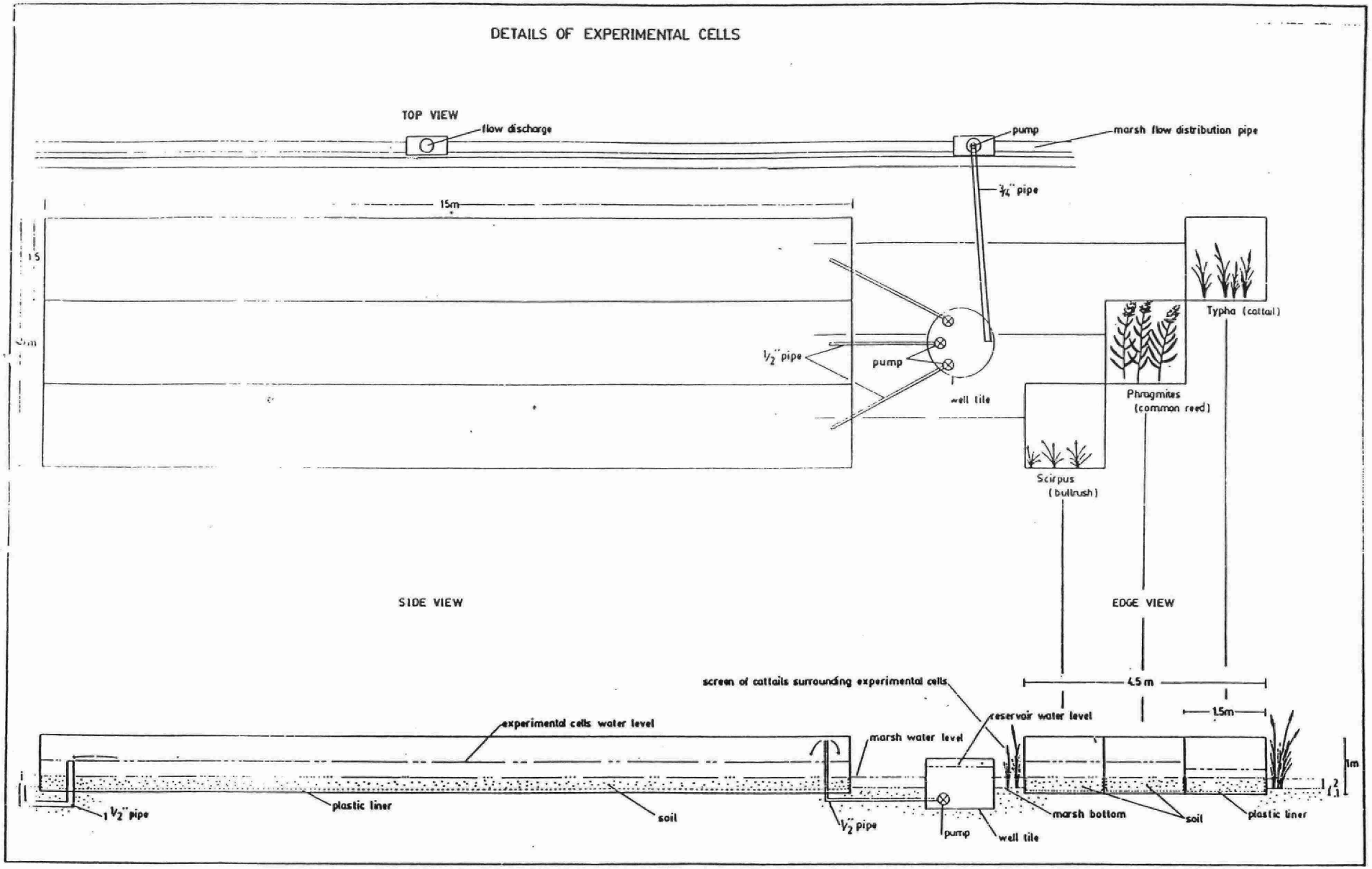

Figure 1. Experimental marsh treatment Facility located at Port Perry, Ontario used to compare the ability of three emergent aquatic plant species for treatment of domestic sewage. Not shown is the control cell.

Table 1: Loading rates, water depth, and theoretical retention times for experimental cells.

	Loading Rate (cubic meters/ha/day)	Water Depth (cm)	Retention Time (days)
1986			
Phragmites	200	10	5
Typha	200	20	10
Scirpus	200	30	15
Control cell	200	30	15
1987			
Phragmites	200	15*	7.5
Typha	200	15	7.5
Scirpus	200	30	15
Control Cell	200	15	7.5
Duckweed Polishing Cell**	600	15	2.5

* water depths adjusted July 7, 1987
** duckweed cell operational July 13, 1987

for selected samples. Concentrations of ammonia, dissolved oxygen and hydrogen sulfide were also determined with field test kits at the experimental site.

In the first year of operation, aeration cell effluent served as influent for the experimental marsh facility. The quality of aeration cell effluent was monitored regularly by the Ministry of the Environment. In the spring of 1987, decommissioning of the aeration cell precluded this source as an influent, and a mixture of raw sewage and lagoon effluent was used to provide a suitable influent. Sampling of the diluted, raw sewage influent was incorporated into the existing sampling program to monitor influent quality.

Initially, water depths were adjusted in each cell to depths that best suited the ecology of each species (Table 1). In the second year of the study program, water depths in each cell were adjusted to 15 cm to compare treatment using similar retention times between cells. Also during July 1987, use of the fourth cell as a control was discontinued in order to establish a duckweed polishing cell. Effluent from the three plant cells was routed to a reservoir from which a mixed influent was pumped to the polishing cell. The duckweed polishing cell was loaded at a rate of 600 m^3/ha/day. Operating parameters for the duckweed polishing cell are given in Table 1. The length to width ratio of the polishing cell was approximately 2:1.

Influent and effluent of the duckweed polishing cell was sampled twice weekly and tested for concentrations of ammonia, dissolved oxygen and hydrogen sulfide with field test kits. Samples of influent and

effluent were also collected in conjunction with the on-going sampling program for laboratory analysis.

Duckweed was harvested regularly from the polishing cell to maintain 75% coverage to ensure crowded growth conditions did not develop. Harvesting also served as a means to remove nutrients from the water column, and an ongoing record of harvested biomass was maintained. The harvested duckweed was dewatered centrifugally using a hand operated salad spinner, and the wet mass determined. Samples of harvested duckweed were dried to determine percent moisture content, and representative samples frozen for subsequent determination of nitrogen, phosphorus and organic content by laboratory analysis. This information would be used to assess the potential of duckweed harvest as a means of nitrogen and phosphorus removal.

Results

Culture and Treatment Capacity of Typha, Scirpus and Phragmites

Loading of the experimental facility began during August of 1986, and sampling of effluents commenced in September, 1986. Table 2 summarizes results of influent and effluent water quality analysis for the experimental plant cells for the 1986 summer period (September to October, 1986), the winter period (November 1986 to February 1987) and the 1987 summer period (May 1987 to November 1987). Table 3 indicates percent removal efficiencies for principal parameters (BOD, suspended solids, ammonia, TKN, total P and coliforms) for each seasonal period. All water quality data for the three periods is presented in Appendices 1 and 2.

Plant growth in the cells developed quickly following loading with aeration cell effluent, and growth of Typha and Scirpus was fully developed by fall, 1986. Biomass of Phragmites, Typha, and Scirpus was measured on October 2, 1986, to be 0.8 kg/m^2, 2 kg/m^2, and 3.2 kg/m^2, respectively. Biomass of Phragmites had increased to 4 kg/m^2 by October, 1987.

Treatment of suspended solids, TKN and ammonia declined during the winter period in all cells. The control cell provided treatment equivalent to the vegetated cells during the winter period. Retention time in all cells became markedly reduced as ice formation reduced treatment volume during December and January. Total freeze-up of all cells occurred by mid-February, 1987.

Table 2: Experimental Cells Influent and Effluent Test Results
Average Values (1986-1987)

Date		Summer (1986)		Winter (1986-1987)		Summer (1987)	
Parameter							
BOD (mg/L)	Influent	16.0	(4)	15.4	(1)	48.2	(12)
	Phragmites	2.5	(4)	4.25	(2)	6.4	(12)
	Typha	1.5	(4)	6.25	(4)	8.2	(12)
	Scirpus	0.9	(4)	5.25	(4)	2.8	(12)
	Control	n/a		4.5	(3)	4.0	(4)
BOD Loading (kg/ha/day)		3.2		3.1		9.6	
S.S. (mg/L)	Influent	10	(3)	17	(1)	81	(12)
	Phragmites	7	(4)	15	(2)	27	(12)
	Typha	4	(4)	18	(4)	18	(12)
	Scirpus	2	(4)	16	(4)	17	(12)
	Control	n/a		22	(3)	6	(4)
Ammonia (mg/L)	Influent	10.4	(4)	12.84	(1)	6.6	(12)
	Phragmites	0.99	(4)	7.9	(2)	0.95	(12)
	Typha	1.19	(4)	12.6	(4)	3.7	(12)
	Scirpus	0.51	(4)	9.24	(4)	2.3	(12)
	Control	n/a		8.6	(3)	0.52	(4)
TKN (mg/L)	Influent	10.3	(4)	14.0	(1)	11.0	(12)
	Phragmites	1.59	(4)	9.25	(2)	1.76	(12)
	Typha	0.98	(4)	13.9	(4)	4.9	(12)
	Scirpus	0.71	(4)	11.1	(4)	3.8	(12)
	Control	n/a		11.4	(3)	3.7	(4)
D.O. (mg/L)	Influent	5.1	(4)	9.9	(1)	4.1	(10)
	Phragmites	5.0	(1)	4.7	(2)	3.2	(10)
	Typha	3.3	(1)	2.9	(4)	1.6	(10)
	Scirpus	5.7	(1)	4.1	(4)	2.9	(10)
	Control	n/a		9.7	(3)	8.8	(3)
Total P (mg/L)	Influent	0.53	(4)	0.54	(1)	2.6	(11)
	Phragmites	0.07	(4)	0.17	(2)	0.50	(11)
	Typha	0.06	(4)	0.17	(4)	0.95	(11)
	Scirpus	0.13	(4)	0.06	(4)	0.81	(11)
	Control	n/a		0.14	(3)	0.30	(4)
H_2S (mg/L)	Influent	n/a		n/a		0.6	(10)
	Phragmites	0	(1)	0	(2)	0.52	(10)
	Typha	0	(1)	0.37	(4)	1.8	(10)
	Scirpus	0	(1)	0	(4)	0	(10)
	Control	n/a		0	(3)	0	(2)

n/a - Data not available

Bracketed numbers indicate sample size

Table 2: Experimental Cells Influent and Effluent Test Results
Average Values (1986-1987) (cont'd)

Date		Summer (1986)		Winter (1986-1987)		Summer (1987)	
Parameter							
NO_3 (mg/L)	Influent	n/a				0.11	(5)
	Phragmites	0.035	(2)			0.03	(5)
	Typha	0.035	(2)			0.04	(5)
	Scirpus	0.025	(2)			0.06	(5)
	Control	n/a				n/a	
Fecal C.	Influent	16900	(4)	31000	(1)	2550000	(9)
	Phragmites	350	(2)	2260	(2)	7340	(9)
	Typha	11	(2)	1700	(4)	41300	(9)
	Scirpus	4	(2)	1550	(4)	2690	(9)
	Control	n/a		200	(3)	60	(2)
Strepto.	Influent	1060	(4)	5400	(1)	84000	(1)
	Phragmites	160	(2)	330	(2)	11900	(1)
	Typha	52	(2)	930	(3)	46000	(1)
	Scirpus	72	(2)	370	(3)	2600	(1)
	Control	n/a		42	(2)		

n/a - Data not available

Bracketed numbers indicate sample size

Table 3: Seasonal Removal Percentages for Selected Parameters

Parameter		Summer (1986) (%)	Winter (1986-1987) (%)	Summer (1987) (%)
BOD (mg/L)	Phragmites	84	72	87
	Typha	90	59	83
	Scirpus	94	66	94
	Control		71	92
S.S. (mg/L)	Phragmites	30	12	67
	Typha	60	0	78
	Scirpus	70	6	79
	Control		0	92
Ammonia (mg/L)	Phragmites	90	61	86
	Typha	88	<5	44
	Scirpus	95	28	65
	Control		33	92
TKN (mg/L)	Phragmites	85	34	84
	Typha	90	<1	55
	Scirpus	93	20	65
	Control		18	66
TP (mg/L)	Phragmites	87	68	81
	Typha	89	68	63
	Scirpus	75	89	69
	Control		75	87
Fecal C.	Phragmites	>95	93	>99
	Typha	>95	>95	>95
	Scirpus	>95	>95	>99
	Control		>99	>99

Startup of operations in the spring of 1987 was delayed until a new influent source was developed for the experimental marsh. The use of diluted raw sewage as feedstock for the experimental facility led to higher organic loadings in 1987 than in 1986 when aeration cell effluent served as feedstock (Table 2). In general, poorer effluent quality was obtained in 1987, presumably as a result of higher organic loadings, as indicated by elevated concentrations of suspended solids, hydrogen sulfide, and reduced concentrations of dissolved oxygen.

Water depths in all cells were adjusted to 15 cm on July 7, 1987. However, the water depth in the Scirpus cell was restored to 30 cm on July 28 in an effort to halt an obvious dieback of Scirpus that was concurrent with the initial depth adjustment. No significant difference in treatment efficacy of the Typha and Phragmites cells was observed as a result of depth changes.

In the first year of operation, leakage prevented filling of the control cell until November. During May and June of 1987, bentonite clay was added to all cells to stop leakage, and phosphorus removal was probably enhanced by absorption to clay particles. Simazine was applied to Phragmites at the end of October, 1987, to ensure no undesirable growth of the species developed within the Port Perry treatment facility. The results presented in Tables 2 are summarized below in terms of individual water quality parameters.

Biological Oxygen Demand (BOD)

All cells provided good reduction of BOD. Influent concentrations

were relatively low in the first year, averaging 15 mg/L, but averaged over 50 mg/L in the second year. Concentrations of BOD in cell effluents were normally below 10 mg/L in all seasons. Little difference in treatment efficacy was observed between 1986 and 1987, though organic loading increased from approximately 3 kg/ha/day (BOD) during 1986 and winter 1987, to approximately 9 kg/ha/day (BOD) during summer, 1987.

Suspended Solids

Similar to BOD, concentrations of suspended solids in the influent increased from the first year to the second, averaging less than 20 mg/L in the first year, and more than 80 mg/L in the second. Treatment efficiency was good by all species (normally greater than 65%), though treatment efficiency declined in the winter. Effluent concentrations of suspended solids normally remained below 20 mg/L, though an overall increase in effluent concentrations of suspended solids was observed in 1987.

Ammonia and TKN

Influent concentrations of ammonia ranged between 5 and 15 mg/L during both years. While all of the cells provided good reduction of ammonia, concentrations of ammonia in cell effluents increased during the winter. Similar to ammonia, good reductions of TKN were achieved during the summer, but declined during the winter period. Phragmites provided the best reduction of TKN during 1987 (approximately 84%), while Typha provided the poorest removal (approximately 55%).

Ammonia concentrations were measured by laboratory analysis and by a Hach test kit in the field. Normally, results obtained by field testing were greater than results obtained by lab analysis. Periodically,

ammonia readings measured in the field exceeded TKN values obtained by laboratory analysis, though this usually occurred only when ammonia concentrations exceeded the upper limits of the test kit (3 mg/L). Values given in Appendix 1 and 2 are normally field test results, but lab analysis results are given when concentrations exceeded 3 mg/L.

Dissolved Oxygen and Hydrogen Sulfide

Dissolved oxygen concentrations in the influent averaged above 5 mg/L in the first year and below 4 mg/L in the second year, attributable to the use of diluted raw sewage as influent in 1987 as opposed to areation cell influent in 1986. Of the experimental cells, dissolved oxygen concentrations were usually lowest in effluent from the Typha cell. In general, effluent concentrations of dissolved oxygen were lower in 1987 than 1986, likely due to higher organic loading in 1987.

While no hydrogen sulfide was detected in cell effluents during the first year, hydrogen sulfide concentrations averaged 2.5 and 0.52 mg/L in effluent from the Typha and Phragmites cell, respectively, during the second summer (1987). Influent concentrations of H_2S averaged 0.6 mg/L during 1987.

Total Phosphates (TP)

Influent concentrations of TP were approximately 0.5 mg/L in the first year, and averaged 2.7 mg/L in the second year. Concentrations of TP were reduced in all cells during both years of the study, though higher effluent concentrations of phosphorus were obtained in 1987 as compared to 1986. Removal rate of phosphorus in the Phragmites cell remained above 80% during both summer periods. Addition of bentonite

clay, as mentioned, in May and June, 1987, most likely reduced effluent phosphorus concentrations by adsorption.

Nitrate

Selected samples of influent and effluent were analysed during the second summer for nitrate concentration. Effluent concentrations averaged below 0.05 mg/L for samples collected in 1987. One set of effluent samples taken on September 26, 1986, recorded nitrate concentrations between 0.5 and 0.7 mg/L for the three plant cells.

Bacteria

Concentrations of bacteria (Fecal coliforms and Streptococcus) were reduced in all cells. Effluent from the Typha cell normally contained the highest concentrations of coliform organisms.

Duckweed Polishing Cell Substudy

The duckweed polishing cell operated for a period of fourteen weeks from mid-July, 1987 to October, 1987. The initial introduction of duckweed fully colonized the cell within five days of filling. Results of bi-weekly and bi-monthly analysis of influent and effluent samples are presented in Appendix 3. Average influent and effluent values for each parameter analyzed are presented in Table 4.

On average, total phophorus concentrations were reduced from approximately 0.7 mg/L to 0.32 mg/L (55% reduction), following treatment in the duckweed polishing cell. Similarily, concentrations of TKN were

Table 4: Duckweed Polishing Cell - Water Quality and Biomass Harvesting Data - Average Results (July to Oct., 1987)

	Field Test Results				Laboratory Analysis Results						
Parameter	Ammonia (mg/L)	SRP (mg/L)	DO (mg/L)	H_2S (mg/L)	Ammonia (mg/L)	BOD (mg/L)	S.S. (mg/L)	TKN (mg/L)	TP (mg/L)	NO_3 (mg/L)	Fecal Coliforms
Influent	3.36	1.68	3.6	0	3.35	3.1	46.5	3.38	0.76	0.045	5120
Effluent	1.12	0.51	10.5	0	1.02	2.1	55.4	1.72	0.29	0.042	682
Sample Size	22	20	16	15	2	7	7	7	6	5	7

reduced from 3.23 mg/L to 1.8 mg/L (45% reduction), and concentrations of ammonia reduced on average from 3.36 mg/L to 1.1 mg/L (67% reduction) (Table 4).

Further reductions in BOD were achieved in the duckweed polishing cell, though influent concentrations were normally less than 5 mg/L. Concentrations of suspended solids in both influent and effluent results were unexplicibly high (generally greater than 30 mg/L), as feedstock for the duckweed cell consisted of effluents of the aquatic plant cells which usually had suspended solids concentrations between 15 and 30 mg/L. However, no suspended materials or plankton algae was normally observable in the influent or effluent of the duckweed polishing cell.

Effluent concentrations of dissolved oxygen were consistently high (ie., greater than 13 mg/L), probably resulting from algae photosynthesis within the polishing cell. No H_2S was detected at any time in either cell influent or effluent. Dissolved oxygen concentrations in the influent increased from less than 1 mg/L early in the study period to 4 mg/L or more by the end of August. Nitrate concentrations were normally less than 0.1 mg/L in influent and effluent samples. Concentrations of fecal coliforms were normally reduced by 80% or more, and effluent concentrations of fecal coliforms averaged less than 700 per millilitre.

Regular harvest of healthy duckweed plants occurred for about two weeks following establishment of a complete cover, and 75% coverage was maintained by harvesting. Beginning in August, however, growth rate and plant vigour declined. Concurrent with the decline in duckweed growth

rate, algae growth developed which entrained the duckweed roots, and occupied portions of open water spaces to the degree that duckweed growth was hindered. Periodically, an attempt was made to clear algae growth from the duckweed cell, though the amount of algae removed was not recorded. To bolster growth of duckweed, healthy duckweed was periodically transplanted into the polishing cell from the adjacent cells.

The average rate of duckweed removal over the duration of the study was approximately 12 g/m^2/day (fresh weight). A maximum biomass removal rate of approximately 50 g/m^2/day (fresh weight) was achieved during the first two weeks of the study before growth rate declined. A total biomass of approximately 6 kg (fresh weight) was harvested through the course of the study, which included an unmeasured amount of algae. Eight samples of harvested duckweed were retained and analyzed for nutrient content. Average content of phosphorus and nitrogen was 0.40% and 2.43%, respectively, on a dry mass basis. The approximate ratio of dry weight to wet weight for selected samples was 0.1.

Discussion

Culture and Treatment Capacity of Typha, Scirpus and Phragmites

Development of thick, homogeneous stands of Phragmites and Scirpus during the study period indicates that these species, like Typha, can tolerate shallow, lagoon environments treating wastewaters of moderate strength. Over the two year study period, no intrusion of one species into adjacent cells was observed, reflecting the ability of the experimental species to develop hardy stands capable of withstanding competition from other emergent species. Thus, where sufficient root stock was available, it would appear possible to establish large and stable treatment facilities with any of the three species evaluated.

Root stock of Typha and Scirpus for the experimental facility were obtained from the cattail marsh cell at the Port Perry water treatment facility. Phragmites root stock were obtained from a location near Brampton, though suitable stands of Phragmites commonly occur throughout southern Ontario. Transplanted material was hand planted at a density of approximately nine root stalks per m^2, and thick continuous growth of Typha and Scirpus developed from initial plantings. Though supplementary transplanting of Phragmites was required in the summer of 1987 to hasten colonization, transplanting of root stock with attached stems and leaves proved to be an effective method of establishing good growth of treatment species. Original water depths selected (10, 20 and 30 cm for Phragmites, Typha and Scirpus, respectively) provided a suitable growth environment for each species.

At several times during the study, raw sewage was accidentally or purposely applied to the cells. Both Scirpus and Phragmites reacted negatively to raw sewage inputs, and dieback of these species might have occurred if loading with raw sewage was continued. Reduced plant health was indicated by slumping plants and loss of colour and vigour in the leaves and stems. Typha, in comparison, appeared to suffer no negative effects from raw sewage loading. Indeed, the raw sewage supply employed during the second year of operation was directed to the Typha demonstration marsh, and overflow from the raw sewage supply standpipe into the demonstration marsh appeared to have little deleterious effects on surrounding cattails.

During the second season, water depth in the experimental cells was adjusted to 15 cm, in order to provide equal retention times in all cells. A severe and rapid dieoff of Scirpus followed the depth adjustment. The water depth was maintained at 15 cm in the Scirpus cell for four weeks, and at no time was there any indication of acclimation to the reduced depth. The dieoff should possibly have been anticipated, as Scirpus is best adapted to deeper waters, and requires support in the lower stem to maintain healthy growth. While some of the dead plant material was removed from the cell, no large increases of BOD, nitrogen or phophorus was recorded in effluent samples following dieoff (Appendix 2). When the water depth in the Scirpus cell was re-adjusted to 30 cm, surviving plants returned to their original vigour within two to three weeks.

While the depth change was greatest in the Scirpus cell (30cm to 15cm), Typha and Phragmites did not suffer any observable negative

effects. This observation is perhaps most interesting in terms of Phragmites health, as Phragmites rarely occurs naturally where surface waters are continuously present.

As results of treatment efficacy of the full scale, cattail marsh at Port Perry have not been published to date, no direct comparison of performance of the experimental facility to the full scale marsh can be made at this time.

Duckweed Polishing Cell

Significant reductions of total Kjedahl nitrogen (TKN), ammonia, and phosphorus were achieved by use of the duckweed polishing cell to treat effluent from the experimental plant cells (Table 3). Best reductions of ammonia and TKN were achieved at the onset of the study, when the best rate of plant growth and plant vigour was experienced. Removal of phosphorus was more consistent through the study period than nitrogen removal. It is anticipated that a longer retention time would have provided better reduction of nitrogen and phosphorus.

Of studied parameters, only suspended solids concentrations were not significantly reduced by the duckweed polishing cell. Other researchers have reported good reductions of suspended solids in similar studies using duckweed (Koles, et al, 1986, McCaleb et al, 1986), and no explanation for the obtained results can be given.

Based on harvest rates and tissue nutrient content analysis, approximately 24 g of nitrogen and 4 g of phosphorus were removed from

the influent by harvest of plants. This estimate is probably conservative as algae growth was periodically removed and discarded from the duckweed cell. Based on loading rates and average influent and effluent concentrations of nitrogen and phosphorus, approximately 42 g of nitrogen and 12 g of phosphorus were removed by use of the duckweed cell. Though estimates of nutrient removal are approximate, 50% of the nitrogen removal and 33% of the phosphorus removal can be attributed to harvest of duckweed. Tissue nutrient content of duckweed samples was relatively low compared to analysis of duckweed from other enriched waters or sewage lagoons (Neil, J.H. et al, 1984), and it is anticipated that healthy growth would have provided better nutrient uptake than was achieved in this study.

The reasons for poor growth of duckweed beginning in August are not fully understood, though heavy growth of algae during the latter part of the study no doubt restricted duckweed growth. Good growth of duckweed was observed throughout the growing season in the adjacent plant cells and the large, cattail treatment marsh. Other researchers have also reported good growth of duckweed early in the growth period followed by poor growth rates, even in managed stands (Whitehead et al., 1986, Koles et al., 1986) and at present, the environmental requirements for sustainable growth and harvest have not been defined.

Conclusions

A number of conclusions results relating to treatment efficacy and plant culture may be drawn from the results of the study.

1) Good reductions in BOD and suspended solids concentrations were achieved by all species. Effluent concentrations were generally less than than 10 and 30 mg/L for BOD and suspended solids, respectively. Treatment efficiency for most of the studied parameters declined during the winter.

2) The experimental results indicate that both Phragmites and Scirpus may be more effective than Typha in treating domestic sewage, particulary in terms of hydrogen sulfide, ammonia, and bacteria reductions.

3) The loss of healthy growth of Scirpus in the second year resulting from reducing the water depth complicates interpretation of effluent data from that cell. In the first year, the Scirpus cell provided the best overall treatment of the experimental species.

4) Further reduction of most wastewater parameters, particulary TKN, NH_3, and P can be achieved by use of a duckweed cover.

5) Management (harvest rates) of duckweed cover should be judicious to avoid development of algae growth and to promote sustainable harvest rates.

6) While longer retention times would probably provide further reduction of wastewater parameters, the relatively short retention time employed in the duckweed cell proved effective in reducing concentrations of N and P by 45% and 55%, respectively.

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Appendix 1: Port Perry - Experimental Cells Influent and Effluent Test Results - Sept. 1986 to Feb. 1987

Date		Sept. 16	Sept. 26	Oct. 7	Oct. 22	Nov. 5	Dec. 3	Jan. 6	Feb. 6
Parameter									
BOD	Influent	16	11.5	23.1	11	15.4	n/a	n/a	n/a
(mg/L)	Phragmites	3	3	2	1	1.5	n/a	7	n/a
	Typha	2.5	2	1	0.5	0.5	5.5	6	13
	Scirpus	1.5	1.5	0.5	0.25	1	5	1	14
	Control	n/a	n/a	n/a	n/a	3.5	6.5	3.5	n/a
S.S.	Influent		15.1	8.8	8.3	17.2	n/a	n/a	n/a
(mg/L)	Phragmites	6	6	9	7	12	n/a	19	n/a
	Typha	1	6	3	7	10	20	15	30
	Scirpus	1	4	1	5	10	14	8	32
	Control	n/a	n/a	n/a	n/a	25	27	15	n/a
Ammonia	Influent	6.54	6.15	10.56	13.32	12.84	n/a	n/a	n/a
(mg/L)	Phragmites	0.48	1.8	0.6	1.1	2.2	n/a	13.6	n/a
	Typha	0.48	0.96	0.72	2.6	7.6	11.5	14	17.5
	Scirpus	0.48	0.48	0.6	0.48	0.07	9.5	11.5	15.9
	Control	n/a	n/a	n/a	n/a	3.2	9.6	12.9	n/a
TKN	Influent	11.8	8.75	10.8	11.8	14	n/a	n/a	n/a
(mg/L)	Phragmites	0.55	1	1.23	3.6	3.6	n/a	14.9	n/a
	Typha	0.71	0.98	0.69	1.53	2.8	12.4	18.3	22
	Scirpus	0.91	0.74	0.6	0.59	0.9	9.7	14.1	20
	Control	n/a	n/a	n/a	n/a	6.8	11.1	16.3	n/a
D.O.	Influent	7.6	3.3	6.5	3	9.9	n/a	n/a	n/a
(mg/L)	Phragmites	n/a	n/a	n/a	5	7	n/a	2.5	n/a
	Typha	n/a	n/a	n/a	3.3	3.7	3	2.5	2.5
	Scirpus	n/a	n/a	n/a	5.7	6.5	5.3	2.5	2.0
	Control	n/a	n/a	n/a	n/a	10.6	16	2.5	n/a
Total P	Influent	0.64	0.53	0.52	0.44	0.54	n/a	n/a	n/a
(mg/L)	Phragmites	0.052	0.081	0.076	0.061	0.12	n/a	0.23	n/a
	Typha	0.029	0.13	0.046	0.037	0.1	0.1	0.15	0.33
	Scirpus	0.026	0.044	0.04	0.031	0.041	0.052	0.1	0.067
	Control	n/a	n/a	n/a	n/a	0.12	0.14	0.16	n/a

n/a - Data not available

Appendix 1: Port Perry - Experimental Cells Influent and Effluent Test Results - Sept. 1986 to Feb. 1987 (cont'd)

Parameter		Sept. 16	Sept. 26	Oct. 7	Oct. 22	Nov. 5	Dec. 3	Jan. 6	Feb. 6
S.R.P. (mg/L)	Influent	n/a	.25/.12	0.38	0.25	0.14	n/a	n/a	n/a
	Phragmites	0	0	0	0	0	n/a	0	n/a
	Typha	0	0	0	0	0	0	0	1.4
	Scirpus	0	0	0	0	0	0	0	1.1
	Control	n/a	n/a	n/a	n/a	0	0	0	n/a
H_2S (mg/L)	Influent				n/a	n/a	n/a	n/a	n/a
	Phragmites				0	0	n/a	0	n/a
	Typha				0	0	0	0	1.5
	Scirpus				0	0	0	0	0
	Control				n/a	0	0	0	n/a
NO_3 (mg/L)	Influent								
	Phragmites	<0.01	0.069						
	Typha	<0.01	0.071						
	Scirpus	<0.01	0.051						
	Control	n/a	n/a						
Fecal C.	Influent	25000*	32000	100	10500	31000	n/a	n/a	n/a
	Phragmites	n/a	n/a	600	100	28	n/a	4500	n/a
	Typha	n/a	n/a	12	10	164	730	340	5600
	Scirpus	n/a	n/a	4	4	4	310	68	5800
	Control	n/a	n/a	n/a	n/a	64	10	530	n/a
Strepto.	Influent	620	730	20	2860	5400	n/a	n/a	n/a
	Phragmites	n/a	n/a	240	80	28	n/a	640	n/a
	Typha	n/a	n/a	84	20	164	n/a	120	2500
	Scirpus	n/a	n/a	140	4	4	n/a	4	1110
	Control	n/a	n/a	n/a	n/a	64	n/a	20	n/a
Pseudo.	Influent	50	90	4	224	240	n/a	n/a	n/a
	Phragmites	n/a	n/a	n/a	n/a	n/a	n/a	100/350	n/a
	Typha	n/a	n/a	n/a	n/a	n/a	n/a	10	300/2120
	Scirpus	n/a	n/a	n/a	n/a	n/a	n/a	4	128/460
	Control	n/a	n/a	n/a	n/a	n/a	n/a	10	n/a

n/a - Data not available

Appendix 2: Port Perry - Experimental Cells Effluent Test Results - May 1987 to Sept. 1987

Date		May 14	June 7	June 16	July 3	July 15	July 28	Aug. 18	Aug. 27	Sept. 10	Sept. 22	Oct. 6	Oct. 19
Parameter													
BOD	Influent	26	22	48	35	20	41	20	74	190	51	20	31
(mg/L)	Phragmites	2	7	5	5	28	8.8	5.3	2	3	4	2.5	4.5
	Typha	1	4	2.9	7	51	6.1	6.2	2	2	4	6.0	6
	Scirpus	1.6	1	3	2	10	3.9	1.7	1.5	1	3	1.0	4
	Control	6	2	3	1								
S.S.	Influent	45	9.7	74	92	24	93	33	330	57	54	50	120
(mg/L)	Phragmites	1	14	2	9	21	9	55	33	80	18	14	77
	Typha	1	11.5	7.5	8	18	5	10	49	50	12	20	27
	Scirpus	1	12	3	2	8	<1	29	19	30	12	28	69
	Control	13	4	4	5								
Ammonia	Influent	3.7	3	7.92	n/a	4.6	2.76	6.12	11.4	9	9.0	8.8	3.4
(mg/L)	Phragmites	0.17	1.68	0.84	0.6	0.91	0.96	0.36	0.6	0.3	0.8	0.8	2.3
	Typha	0.1	2.04	5.4	1.92	6.8	6.7	2.9	0.72	1.1	4.8	10.4	5.6
	Scirpus	0.23	0.72	2.64	1.32	6	1.4	2.16	0.96	0.6	4.5	3.0	6.4
	Control	0.2	0.6	0.84	0.84								
TKN	Influent	13.2	8.1	11.5	19.3	7.7	10.5	8.6	21	10.8	13	10.8	7.5
(mg/L)	Phragmites	2.1	2.7	1.73	1.84	3.1	1.69	1.27	1.09	0.89	1.14	1.25	2.4
	Typha	1.83	3.2	5.5	2.5	10.7	5.2	3.3	1.19	1.46	5.2	11.7	7.0
	Scirpus	2.1	3.6	2.9	1.77	7.7	2	2.3	1.6	0.92	4.9	3.3	5.3
	Control	7.5	3.1	2.5	1.7								
D.O.	Influent	n/a	3.4	3.5	8	7	2.2	0.5	2	n/a	<1	6.0	8.0
(mg/L)	Phragmites	n/a	5.8	4	1	2.2	2.5	3.3	5.5	n/a	1.0	3.0	4.0
	Typha	n/a	3.3	0.8	0.5	0.8	1.9	3	2.6	n/a	<1	<1	2.0
	Scirpus	n/a	4.5	1.5	3	2	1.6	3.3	3.5	n/a	1.5	4.0	4.0
	Control	n/a	12.4	9.5	4.5								
Total P	Influent	0.66	2.7	4	2.2	1.77	3.5	1.48	5.3	n/a	3.2	1.85	2.1
(mg/L)	Phragmites	0.046	0.65	0.135	0.11	1.74	1.45	0.26	0.06	n/a	0.28	0.08	0.72
	Typha	0.062	0.23	0.47	0.23	2.12	1.94	1.46	0.3	n/a	1.55	1.57	0.49
	Scirpus	0.121	0.12	0.39	0.24	2.41	1.36	2.6	1.02	n/a	0.55	0.09	0.04
	Control	0.38	0.4	0.24	0.16								

n/a - Data not available

Appendix 2: Port Perry - Experimental Cells Influent and Effluent Test Results - May 1987 to Sept. 1987 (cont'd)

Date		May 1	June 7	June 16	July 3	July 15	July 28	Aug. 18	Aug. 27	Sept. 10	Sept. 22	Oct. 6	Oct. 19
Parameter													
S.R.P. (mg/L)	Influent	n/a	2.8	4.2	3.4	2.8	3.9	2.5	2.5	0.4	5.0	3.0	2.3
	Phragmites	n/a	1.8	0	0.6	3.2	3.8	0.4	0	<0.2	0.8	0	0.5
	Typha	n/a	0.5	1	0.4	1.9	2.7	3.8	0.9	1.9	4.4	4.5	2.4
	Scirpus	n/a	0	1.5	0.7	5	3.5	n/a	2.7	<0.2	1.6	0.4	0
	Control	n/a	0.85	0.8	0.5								
H_2S (mg/L)	Influent	n/a	n/a	0.2	0	0	<1	0	1	1	1.5	0.7	1
	Phragmites	n/a	n/a	0	0	5	0	0	0	0	0.1	0	<0.1
	Typha	n/a	n/a	2.3	5	5	5	0	0	0	0.4	0	0.7
	Scirpus	n/a	n/a	0	0	0	0	<1	0	0	0	0	0
	Control	n/a	n/a	0	0								
NO_3 (mg/L)	Influent							<.01	0.04	0.12	0.12	0.28	
	Phragmites							<.01	<.01	0.08	<0.04	<0.04	
	Typha							<.01	<.01	0.04	<0.04	0.16	
	Scirpus							0.02	<.01	0.08	0.08	0.12	
Fecal C.	Influent	n/a	350000	2700000	n/a	4000000	n/a	710000	7700000	1800000	3900000	1320000	460000
	Phragmites	n/a	4600	20	n/a	57000	n/a	60	9	160	1800	1160	1350
	Typha	n/a	11200	10300	n/a	168000	n/a	4600	120	2000	100000	74000	1800
	Scirpus	n/a	640	860	n/a	17000	n/a	640	180	360	4500	10	10
	Control	n/a	<20	110	n/a								
Strepto.	Influent					84000							
	Phragmites					11900							
	Typha					46000							
	Scirpus					2600							

n/a - Data not available

Appendix 3: Duckweed Polishing Cell - Water Quality and Biomass Harvesting Data

Date		July 15	July 20	July 24	July 28	July 31	Aug. 3	Aug. 7	Aug. 18	Aug. 24
Parameter										
Ammonia (mg/L)	Influent	10.8	5.7	3.36	3.48	2.5	1.4	1.3	1.44	0.6
	Effluent	2.2	0.48	1.2	0.72	0.96	0	0.5	0.48	0.36
S.R.P (mg/L)	Influent	n/a	3.5	4	2.5	3.9	3.24	4.3	n/a	0.7
	Effluent	n/a	0	1.1	1.5	0.7	0.6	2	n/a	0.5
D.O. (mg/L)	Influent	0.8	n/a	1.3	1.7	n/a	1.2	n/a	3.6	0
	Effluent	7.5	n/a	5	6.6	n/a	7	n/a	7.3	8
H_2S (mg/L)	Influent	n/a	n/a	n/a	0	n/a	0	0	0	n/a
	Effluent	n/a	n/a	n/a	0	n/a	0	0	0	n/a
B.O.D. (mg/L)	Influent				5.7				2.7	
	Effluent				2.3				2.4	
S.S. (mg/L)	Influent				38				46	
	Effluent				8				44	
TKN (mg/L)	Influent				3.9				1.82	
	Effluent				1.4				1.09	
TP (mg/L)	Influent				1.67				0.96	
	Effluent				0.59				0.56	
NO_3 (mg/L)	Influent								0.03	
	Effluent								<.01	
Harvested Duckweed Wet Mass (g)		572	710.5	2149.5	857	665	206	410	320.5	181
Fecal C. Duckweed	Influent				n/a				20	10000
	Effluent				n/a				3400	10

Appendix 3: Duckweed Polishing Cell - Water Quality and Biomass Harvesting Data (cont'd)

Date		Aug. 27	Sept. 10	Sept. 14	Sept. 18	Sept. 22	Sept. 25	Sept. 29	Oct. 2	Oct. 6
Parameter										
Ammonia (mg/L)	Influent	0.6	0.6	1.44	1.68	4.56	2.4	1.8	3.0	7.2
	Effluent	0.72	0.6	0.42	0.72	0.36	0.6	0.6	0.5	2.6
S.R.P (mg/L)	Influent	1.2	0.7	0.5	0.7	2	0.6	1.3	1.7	1.4
	Effluent	0.7	0	0	0.3	0.4	0.3	0.3	0	0.7
D.O. (mg/L)	Influent	6.5	n/a	n/a	4	4	n/a	7	5	5
	Effluent	8	n/a	n/a	11	15	n/a	10	14	14
H_2S (mg/L)	Influent	0	0	0	0	0	0	0	0	0
	Effluent	0	0	0	0	0	0	0	0	0
B.O.D. (mg/L)	Influent	2	2.5			4.0				0.5
	Effluent	1.5	1			3.5				1.5
S.S. (mg/L)	Influent	86	61			24				16
	Effluent	79	32			58				34
TKN (mg/L)	Influent	1.76	0.92			4.3				6.0
	Effluent	1.28	0.99			1.15				2.5
TP (mg/L)	Influent	0.45	n/a			0.63				0.70
	Effluent	0.24	n/a			0.11				0.18
NO_3 (mg/L)	Influent	<.01	0.08			0.04				0.08
	Effluent	0.08	<.04			0.04				0.08
Harvested Duckweed Wet Mass (g)		336	591	1121	1031	750	81	89	0	900
Fecal C.	Influent	10000	220			7700				8400
	Effluent	10	30			60				530

Appendix 3: Duckweed Polishing Cell - Water Quality and Biomass Harvesting Data (cont'd)

Date		Oct. 13	Oct. 16	Oct. 19	Oct. 23
Parameter					
Ammonia (mg/L)	Influent	6.8	6.4	4.8	3.4
	Effluent	5.2	4.0	3.4	2.7
S.R.P (mg/L)	Influent	0	0	0.9	0.4
	Effluent	0.9	0	0	0.2
D.O. (mg/L)	Influent	4	6	5	4
	Effluent	14	14	14	13
H_2S (mg/L)	Influent	0	0	0	0
	Effluent	0	0	0	0
B.O.D. (mg/L)	Influent			4.0	
	Effluent			2.5	
S.S. (mg/L)	Influent			55	
	Effluent			52	
TKN (mg/L)	Influent			5.0	
	Effluent			3.8	
TP (mg/L)	Influent			0.15	
	Effluent			0.09	
NO_3 (mg/L)	Influent				
	Effluent				
Harvested Duckweed Wet Mass (g)		132	0	0	
Fecal C. Duckweed	Influent			320	
	Effluent			80	

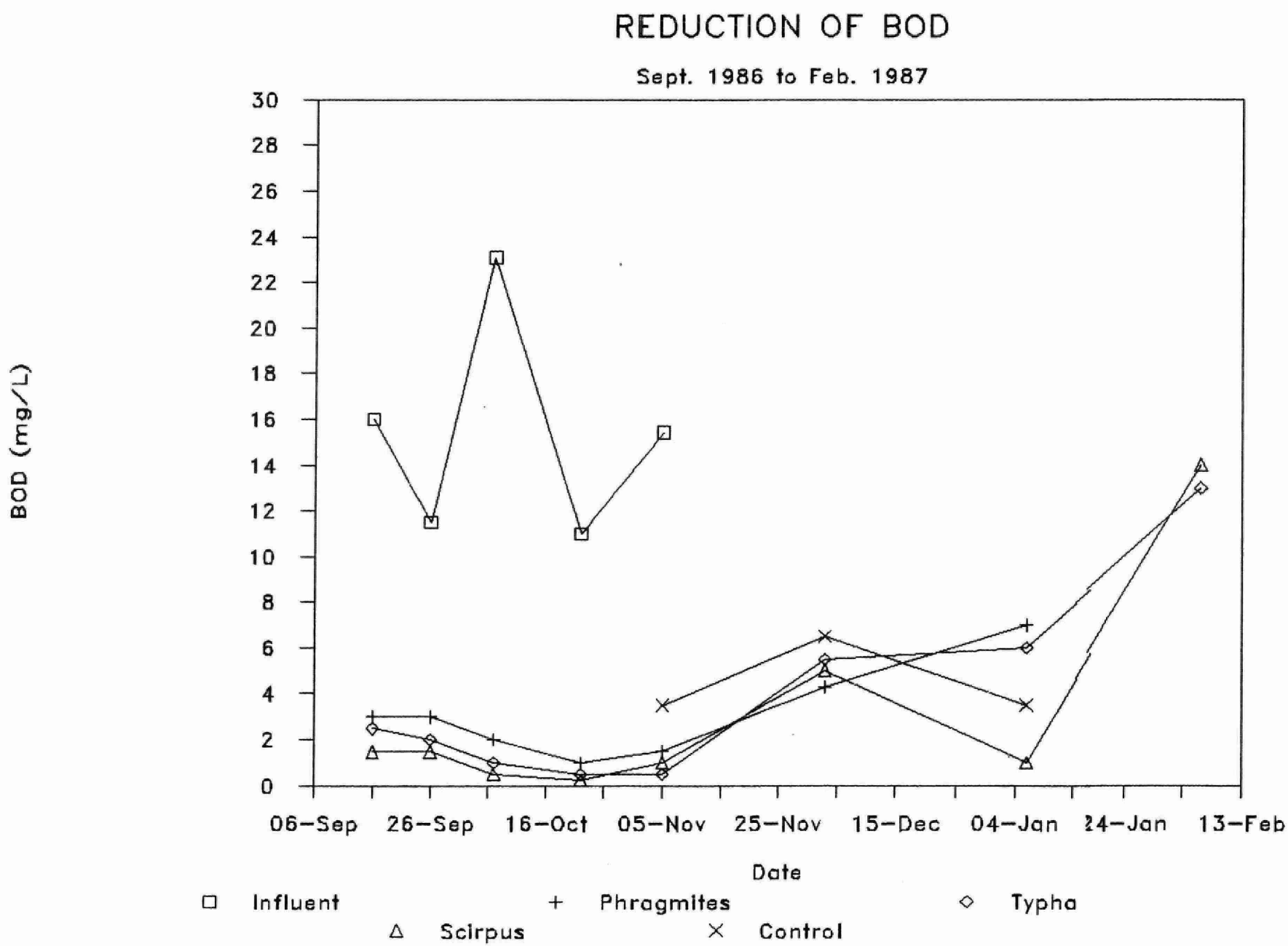

Figure 2. Reduction of BOD in Vegetated and Control Cells Receieving Domestic Wastewater (pre-aerated). September, 1986 to February, 1987.

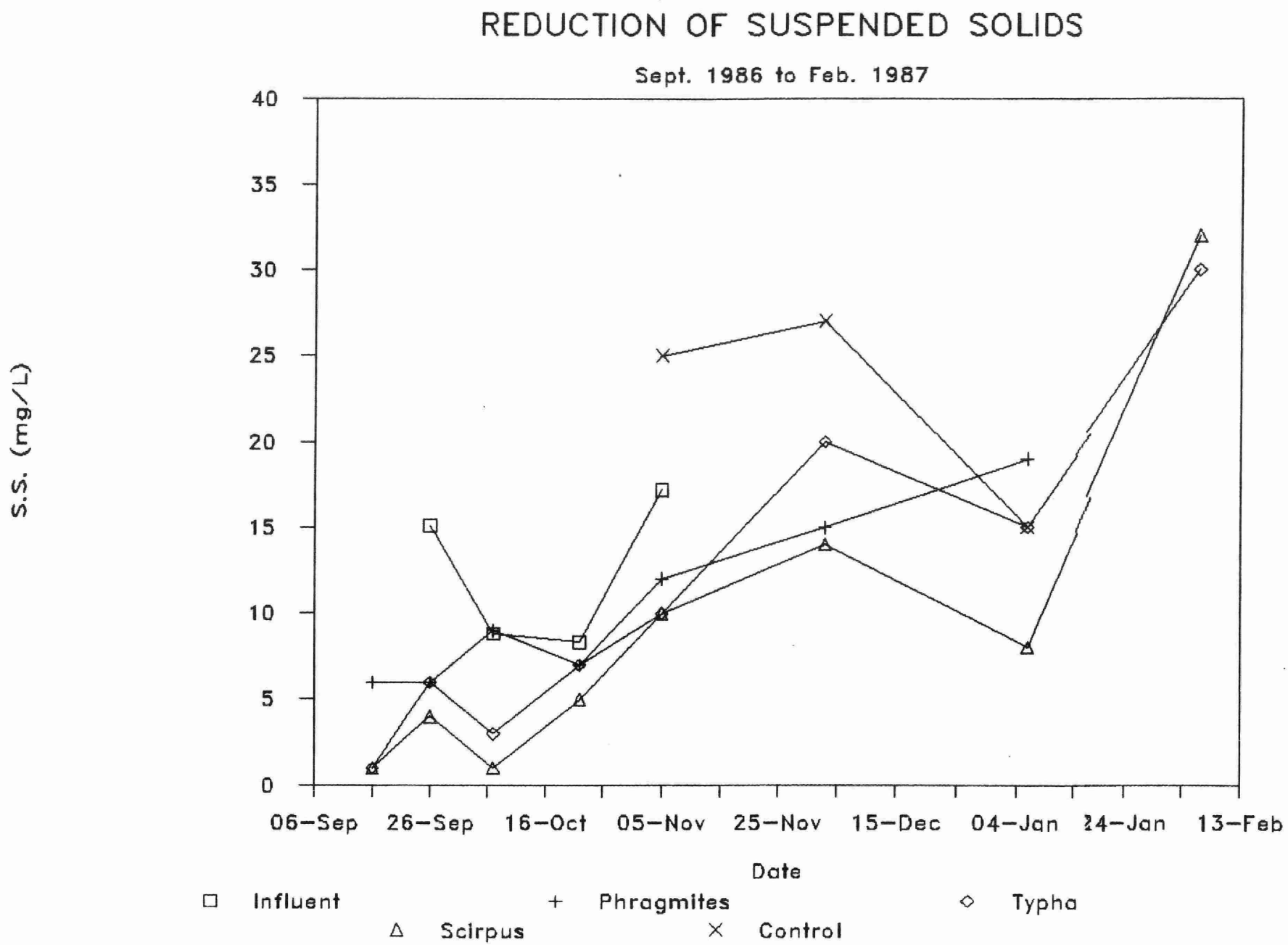

Figure 3. Reduction of Suspended Solids in Vegetated and Control Cells Receiving Domestic Wastewater (pre-aerated). September, 1986 to February, 1987.

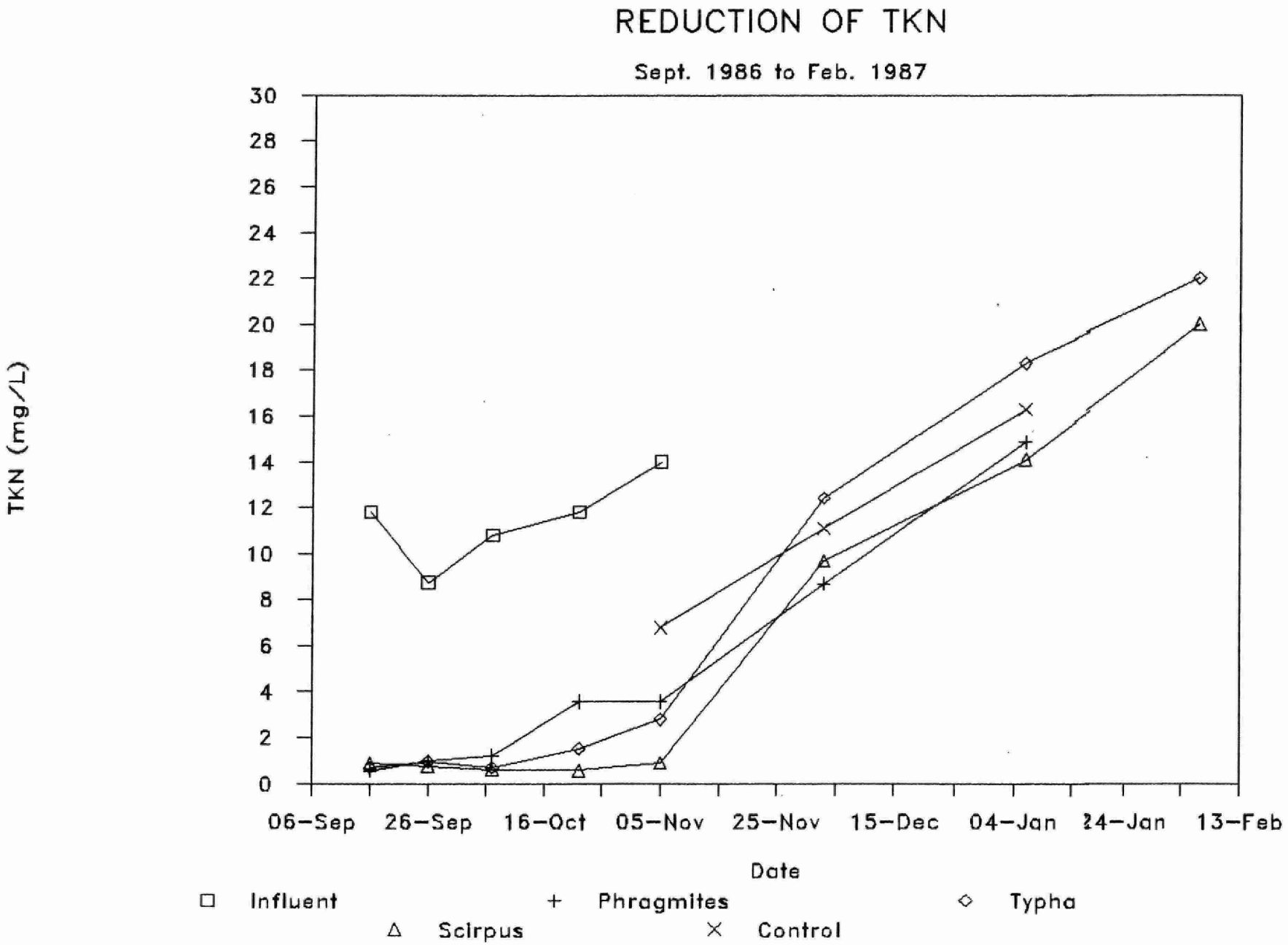

Figure 4. Reduction of TKN in Vegetated and Control Cells Receiving Domestic Wastewater (pre-aerated). September, 1986 to February, 1987.

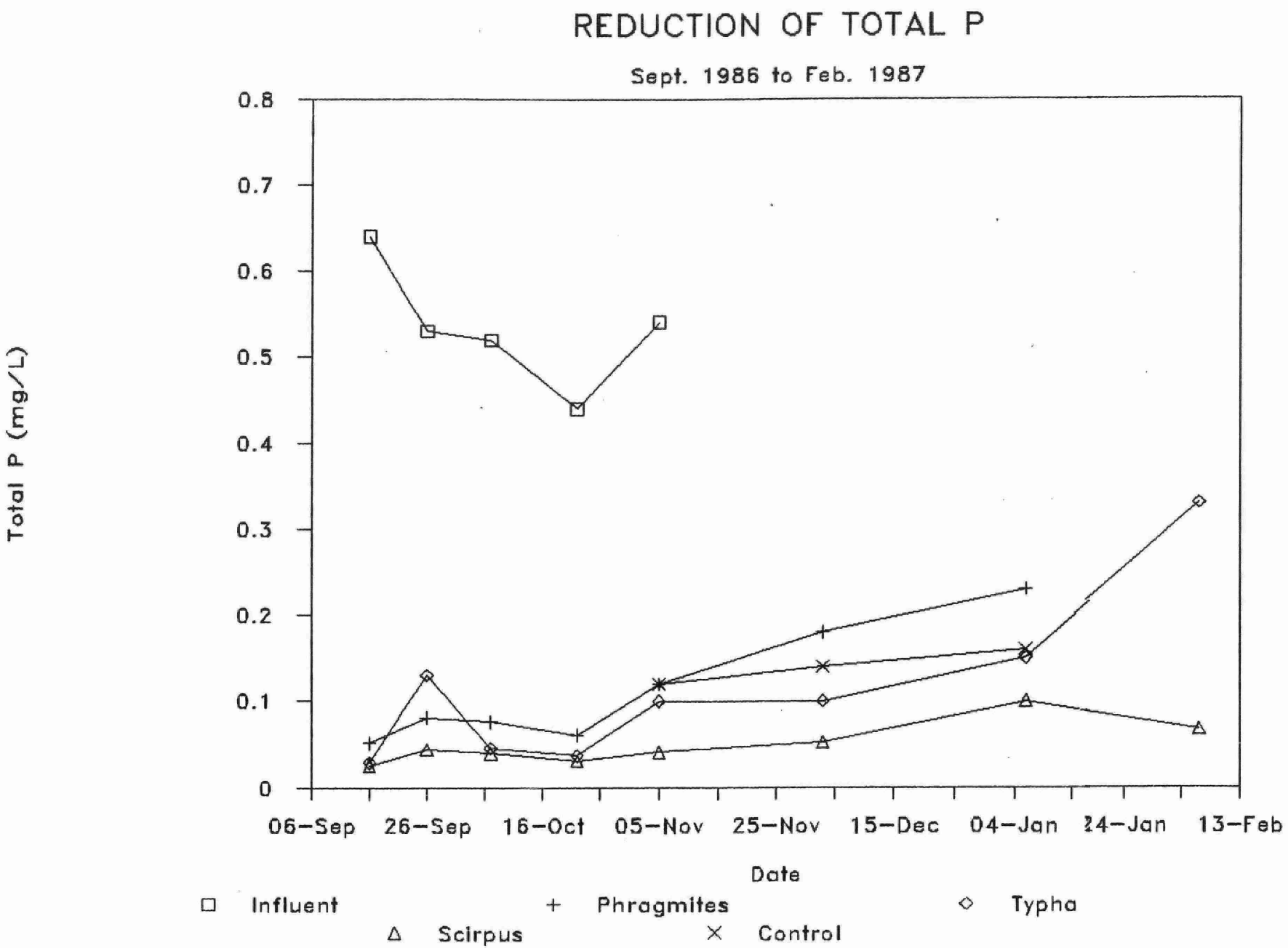

Figure 5. Reduction of Total P in Vegetated and Control Cells Receiving Domestic Wastewater (pre-aerated). September, 1986 to February, 1987.

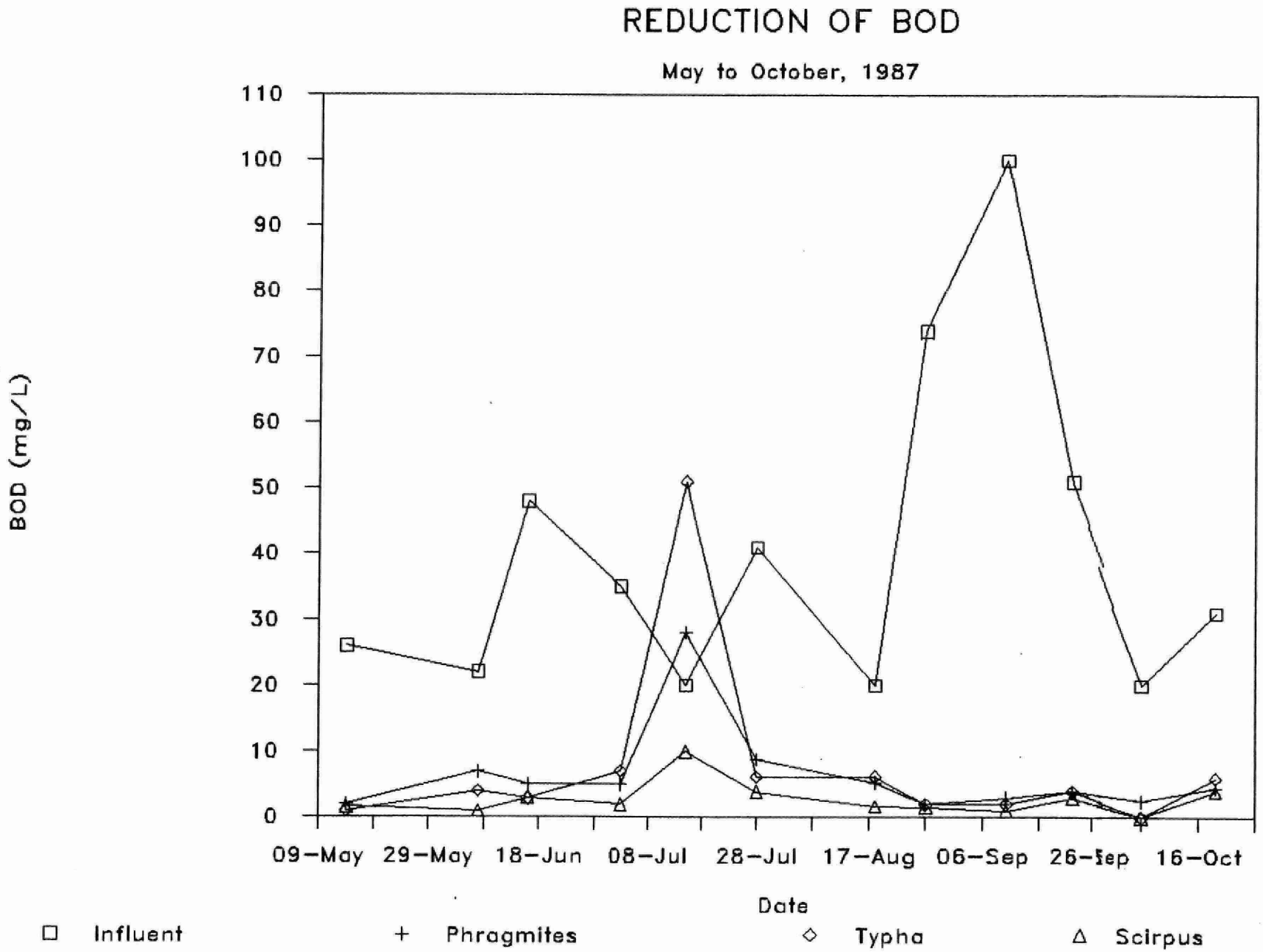

Figure 6. Reduction of BOD in Vegetated Cells Receiving Domestic Wastewater (pre-aerated). May, 1987 to October, 1987.

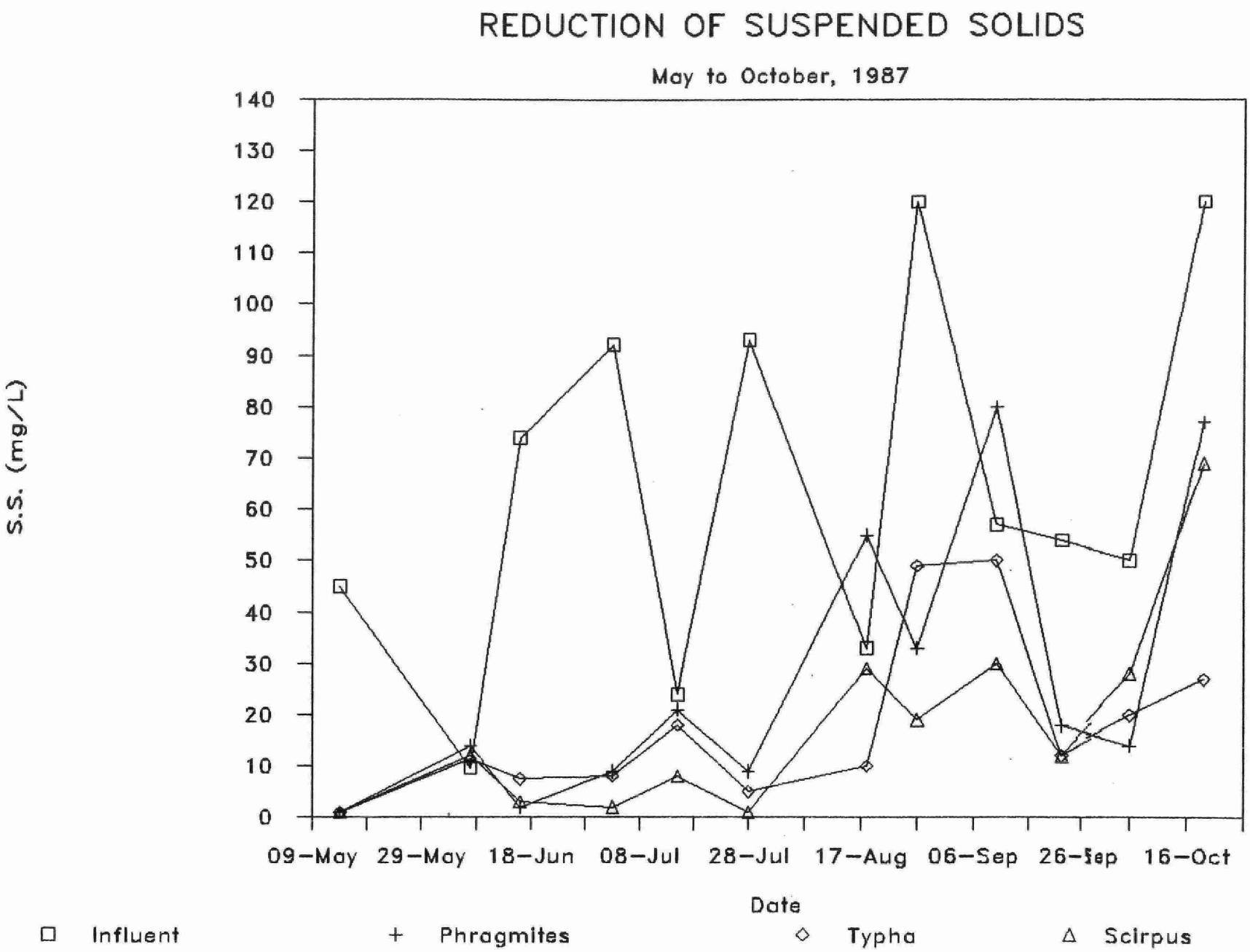

Figure 7. Reduction of Suspended Solids in Vegetated Cells Receiving Domestic Wastewater (pre-aerated). May, 1987 to October, 1987.

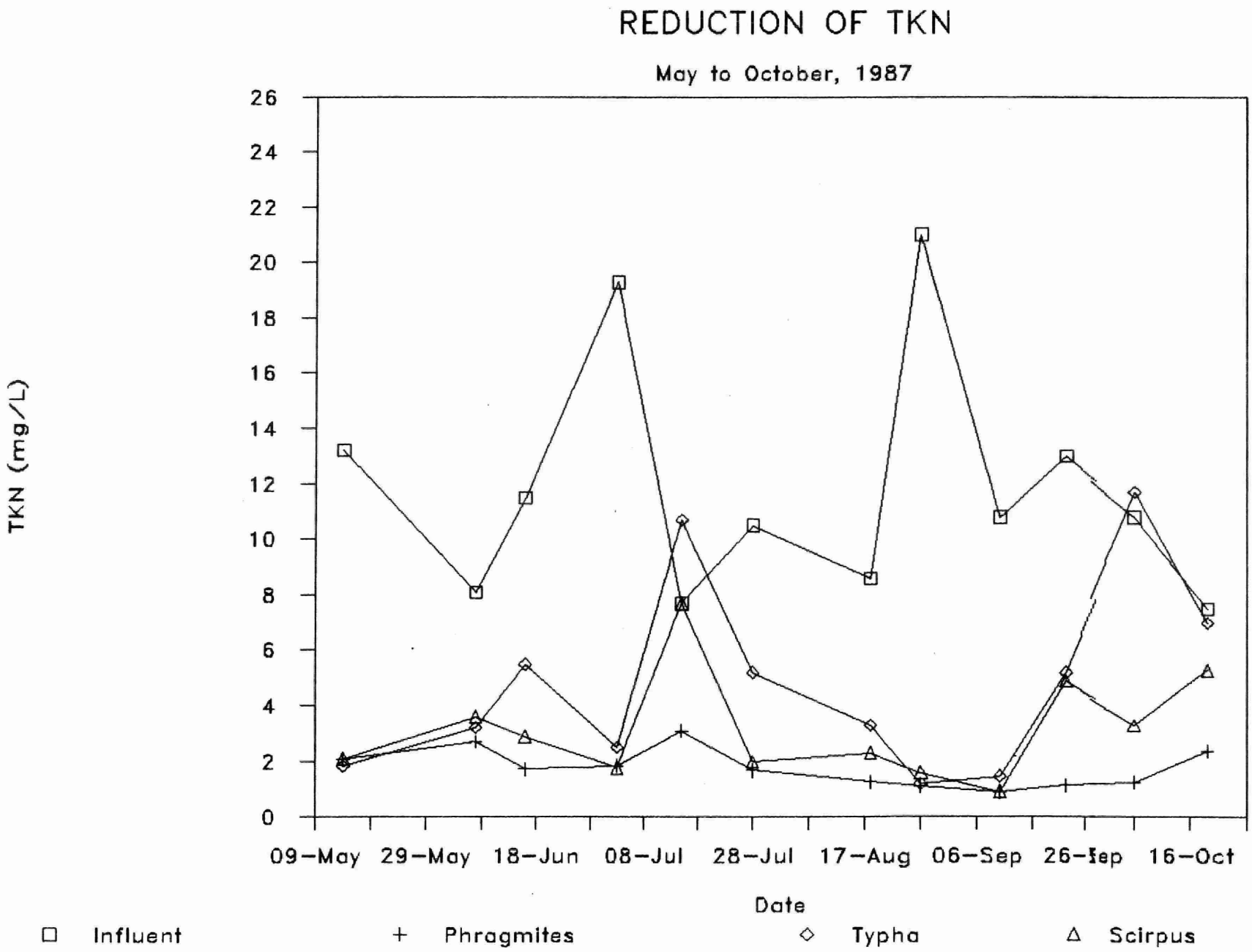

Figure 8. Reduction of TKN in Vegetated Cells Receiving Domestic Wastewater (pre-aerated). May, 1987 to October, 1987.

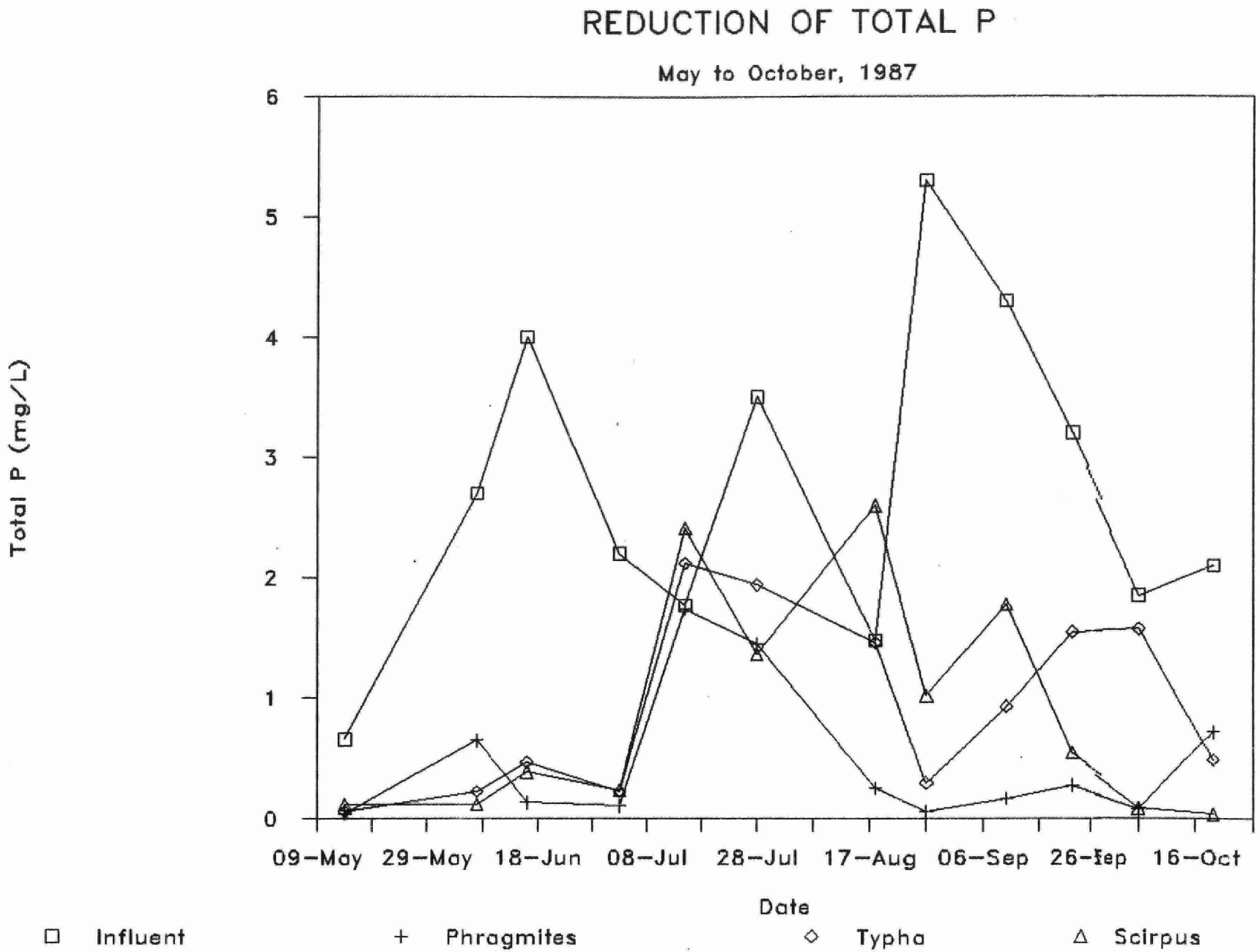

Figure 9. Reduction of Total P in Vegetated Cells Receiving Domestic Wastewater (pre-aerated). May, 1987 to October, 1987.